

TITLE:

RADIOCHEMICAL DETERMINATION OF CCRMP REFERENCE MATERIAL FOR
CERTIFICATION PURPOSES: LEAD 210 ACTIVITY MEASUREMENTS

FINAL REPORT

BY

ELDORADO RESOURCES LIMITED

Work on this project was conducted under the auspices of the
Canada Centre for Mineral and Energy Technology, Energy
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CANMET Scientific Authority: Dr. C.W. Smith

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INTRODUCTION

This report contains the necessary information for completion of DSS contract number OSQ83-00163 as outlined in Section 6, Appendix A of the contract.

The results contained in this report were determined by the Analytical Services Group of Research and Development, Eldorado Resources Limited, located in Tunney's Pasture, Ottawa, Ontario. The project supervisor was Mr. M.C. Miedema. All determinations were carried out by Mr. G.B. Moodie.

A copy of the method used for the determination of ^{210}Pb is attached as Appendix A. Only a single extraction of ^{210}Bi was made as the samples had been captive for over 10 half lives of ^{210}Bi . The results of the determinations are contained in Table 1.

Non-radioactive bismuth in DH-1(a) caused high bismuth recoveries and was corrected for. Incomplete dissolution of DH-1(a) using the outlined procedure was also found and corrected for by adding carriers at the earliest step.

The listed uncertainties are 95% confidence limits determined by multiplying the propagated uncertainty by the factor 1.96. A sample of how the errors were propagated is contained in Appendix B.

Table 1. ^{210}Pb results for CCRMP materials.

Sample	Sub-Sample Mass g	^{210}Pb Activity Bq/g*
DH-1 (a)	1.2087	28.1±1.4
DH-1 (a)	1.2334	28.2±1.4
DH-1 (a)	1.1453	29.6±1.4
DH-1 (a)	1.2991	29.0±1.4
DL-1 (a)	1.2241	1.35±0.06
DL-1 (a)	1.2042	1.34±0.06
DL-1 (a)	1.6309	1.44±0.06
DL-1 (a)	1.3290	1.36±0.06
BL-4 (a)	1.1933	16.1±0.8
BL-4 (a)	1.7709	17.0±0.8
BL-4 (a)	1.0906	16.6±0.8
BL-4 (a)	1.0021	16.2±0.8
BL-5	1.0374	860±40
BL-5	1.3519	870±40
BL-5	1.1074	860±40
BL-5	1.0495	870±40

*Uncertainties are 95% confidence limits calculated by multiplying the propagated uncertainty by 1.96.

APPENDIX A

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ANALYTICAL PROCEDURE

METHOD NO: ERL: 210Pb:1

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ORIGINAL METHOD NO:

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Counting of Its ^{210}Bi Daughter

By: M.C. Miedema and G.A. Dunlop
Research and Development, Ottawa

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PAGE

PARAGRAPH

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Method Review Committee

1. Outline of Method

Lead and bismuth carriers are added to the aqueous sample which is 2N in HCl. Ascorbic acid is added to reduce interfering ferric ions to ferrous. Bismuth along with ^{210}Bi is extracted into diethylammonium diethyldithiocarbamate (DDTC) in chloroform. If the sample is known to be originally in secular equilibrium the organic extract is wet ashed with nitric acid. The bismuth residue is taken up in dilute nitric acid and the bismuth is precipitated as bismuth hydroxide by addition of ammonia. The bismuth is purified by re-dissolving in concentrated HCl and bismuth oxychloride precipitated by dilution with water. The bismuth precipitate is filtered onto a membrane filter which is first dried then counted on a beta counter.

The recovery of bismuth through the extraction stage is determined by atomic absorption spectrophotometry. the ^{210}Pb concentration can be backcalculated using radiochemical formulas. For samples that are not known to be in equilibrium the first organic extract may be discarded. The ^{210}Bi is allowed to grow back into the aqueous phase for a known period of time. Bismuth carrier is again added to the aqueous phase and extracted into DDTC and chloroform. The organic phase is then carried through the procedure outlined above.

2. Interferences

Metal ions forming stronger complexes with DDTC than bismuth will interfere. Most severe are Fe^{3+} , and Cu. Others include Ag, Hg, Sb, Tl, Mo^{4+} , Se, Te, Pb and Pt. Reference 5.1.

3. Concentration Range

37 - 37,000 mBq (1-1000 pCi). Sample aliquot size is chosen to be within this range.

4. Precision*

At the 392mBq(10.6 pCi) level $\pm$ 44mBq(1.2 pCi)(1 σ)n=13
At the 507mBq(13.7 pCi) level $\pm$ 96mBq(2.6 pCi)(1 σ)n=8
At the 1465mBq(39.6 pCi) level $\pm$ 117mBq(3.2 pCi)(1 σ)n=6
At the 2794mBq(75.5 pCi) level $\pm$ 192mBq(5.2 pCi)(1 σ)n=4
At the 21570mBq(583 pCi) level $\pm$ 3480mBq(94 pCi)(1 σ)n=3

* Based on replicate determinations.

5. Reference

- 5.1 G.L. Smithson, J.L. Dalton, G.L. Mason; Radiochemical Procedures for Determination of Selected Members of Uranium and Thorium Series. CANMET REPORT NO. 78-22.
- 5.2 Research and Development Division, Quarterly Report 79-4.
- 5.3 Laboratory Notebook GD-79C
- 5.4 Laboratory Notebook GD-79D
- 5.5 Laboratory Notebook GD-80A

6. Reagents

- 6.1 Chloroform Analytical Grade
- 6.2 Diethylammonium diethyldithiocarbamate (DDTC) Eastman Kodak
- 6.3 Extractant (0.1% DDTC) 0.5g DDTC in 500 mL chloroform. Make fresh daily.
- 6.4 Bismuth Nitrate, $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$
- 6.5 Lead Nitrate $\text{Pb}(\text{NO}_3)_2$
- 6.6 Nitric Acid (HNO_3 , sp gr 1.42) Concentrated, Reagent Grade
- 6.7 Mixed Pb-Bi carrier 2.321g of $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ and 1.598g of $\text{Pb}(\text{NO}_3)_2$ in 100 mL of 10% HNO_3 .
- 6.8 Bismuth Carrier 11.605g $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ in 1000 mL of 10% HNO_3 .
- 6.9 Perchloric Acid (HClO_4 , 62%) Concentrated, Reagent Grade
- 6.10 Hydrochloric Acid (HCl , sp. gr. 1.19) Concentrated, Reagent Grade
- 6.11 Sulphuric Acid (H_2SO_4 , sp. gr. 1.84) Concentrated, Reagent Grade
- 6.12 210Pb Standard Amersham RBZ.44 or RBZ.39.

6.13	Ethanol	30% V/V in water.
6.14	L-ascorbic acid	
6.15	Ammonium hydroxide	Reagent Grade
6.16	Bi Standard	Fisher SO-B-163
6.17	Hydrofluoric Acid (HF, 48%)	Concentrated, Reagent Grade
7.	<u>Preparation of Standards</u>	
7.1	Determination of Counter Efficiency	See Appendix I
7.2	Determination of Bismuth Recovery	See Appendix II
8.	<u>Apparatus</u>	
8.1	B Counter	Canberra 2200 or 2201 low background Gross α/β counting system or equivalent.
8.2	Atomic Absorption Spectrophotometer	Varian AA-6 with Varian 9176 recorder or equivalent.
8.3	Membrane Filtering Apparatus	Sartorius Cat. No. SM 16306
8.4	Membrane Filters	Polyvinylchloride 0.6 μ pore size, 25mm diameter Millipore Cat. No. BDWP 02500. Hydrophobic Filters. 0.45 μ pore size, 25mm diameter Sartorius Cat. No. SM 12806 or SM 11806.
8.5	Aluminum Foil	Standard kitchen weight foil. (.025mm)
8.6	Separatory Funnels	Standard 1000 mL with teflon stopcocks.
8.7	Volumetric Flasks	10 and 25 mL capacity
8.8	Centrifuge	Complete with centrifuge tubes.

8.9 Stainless steel planchet 29mm diameter

8.10 Eppendorff pipet.

9. Procedure

9.1 Preparation of Ore, Rock and Soil Samples

9.1.1 Weigh a lg sample into a 250 mL beaker.

9.1.2 Rinse down sides of beaker with 2 mL distilled deionized water.

9.1.3 Add 10 mL HNO_3 (sp. gr. 1.42) and 10 mL HClO_4 (62%).

9.1.4 Add 1.0 mL of mixed carrier solution.

9.1.5 Evaporate on a hot plate until approximately 1 mL of solution remains. (a)

(a) If necessary, repeat 9.1.3 and 9.1.5.

9.1.6 Allow the solution to cool.

9.1.7 Add 50 mL of 10% HCl and boil for 5 minutes.

9.1.8 Allow the solution to cool.

9.1.9 Transfer the contents to a centrifuge tube and centrifuge.

9.1.10 Return the solution to its original 250 mL beaker.

9.1.11 Transfer the solid residue to a teflon beaker, washing with distilled, deionized water.

9.1.12 Add 2 mL H_2SO_4 (sp. gr. 1.84) acid and 10 mL of hydrofluoric acid to teflon beaker.

9.1.13 Evaporate slowly until approximately 2 mL of the solution remains.

9.1.14 Add 20 mL of 10% hydrochloric acid. (b)

(b) If any precipitate remains, centrifuge the sample and discard the residue.

9.1.15 Combine solution or supernate from 9.1.14 with solution from 9.1.10.

9.1.16 Add 25 mL HCl(sp. gr. 1.19) and dilute to 200 mL with H₂O.

9.1.17 Heat the sample until it just begins to boil.

9.1.18 Remove the sample from the source of heat and add ascorbic acid until the sample colour goes from yellow to clear and add 0.5g excess.

9.1.19 Continue from 9.3.1.

9.2 Preparation of Water Samples

9.2.1 For samples acidified with nitric or hydrochloric acids that are clear or have been filtered, take a suitable aliquot up to a maximum of 800 mL and place in an appropriately sized beaker.
(c)

(c) A suitable aliquot will depend on sample available and estimated concentration. No more than 37 Bq should be taken to prevent possible contamination of detector. Larger samples may be taken, however they require a larger separatory funnel.

9.2.2 Acidify the sample with HCl (sp. gr. 1.19) so that it is 2M hydrochloric acid. (d)

(d) An 800 mL sample requires the addition of approximately 160 mL HCl. HCl (sp. gr. 1.19) is 12N.

9.2.3 Add 1.0 mL of mixed carrier solution and continue from 9.3.1 if the sample is clear.

9.2.4 If the sample contains organic or suspended matter, take an aliquot and place into an appropriately sized beaker.

9.2.5 Add 1.0 mL of the mixed carrier solution and 10 mL of HNO_3 (sp. gr. 1.42) and 3 mL of HClO_4 (62%).

9.2.6 Evaporate on a hot plate until heavy white fumes of HClO_4 are given off. (e)

(e) Repeat acid addition until no organic matter remains.

9.2.7 Dilute to 165 mL with distilled deionized water.

9.2.8 Add 35 mL of HCl (sp. gr. 1.19) and continue from 9.3.1.

9.3 Analysis of Samples

9.3.1 Transfer the sample into an appropriately sized separatory funnel. (f)

(f) Normally a 1L separatory funnel is used.

9.3.2 Add 10 mL of 0.1% DDTC extractant for sample volumes up to 400 mL and 20 mL extractant for greater sample volumes.

9.3.3 Shake the sample vigorously for one minute and note the time. (g)

(g) The time of this first extraction is used to calculate ^{210}Bi decay.

9.3.4 Draw off the organic extract into a 150 mL beaker.

9.3.5 Repeat the extraction until a colourless extract is obtained. (h)

(h) This normally takes three extractions.

Copper in the sample will show a dark brown extract. If the amount of copper exceeds 2mg, the number of extractions needed to recover the bismuth becomes excessive. To overcome this, separate the copper from the bismuth by extracting the copper at a hydrochloric acid concentration of 7 to 8M using 1% DDTC in chloroform. Dilute the sample to 2M and extract the bismuth as in 9.3.2 to 9.3.5.

Iron in the sample will cause an initial colourless extract. To eliminate this, boil the sample on a hot plate and add L-ascorbic acid until the solution goes clear, add 0.5g in excess.

9.3.6 For samples that have been collected less than 30 days previous discard the extract and let the sample sit for a known period of ingrowth time. Add 1.0 mL bismuth carrier, then start at 9.3.1. (1)

(1) The ingrowth time will be the time between the two first extractions.

For samples that have been captive for greater than 30 days or extracted previously and had suitable ingrowth period, continue with 9.3.7.

- 9.3.7 Combine all the extracts and evaporate to dryness.
- 9.3.8 Add 5 mL of HNO_3 (sp. gr. 1.42) and evaporate to dryness.
- 9.3.9 Add another 5 mL of HNO_3 (sp. gr. 1.42) and heat gently on a hot plate for 2 minutes.
- 9.3.10 Remove and allow to cool to room temperature.
- 9.3.11 Transfer the solution into a 25 mL volumetric flask, rinsing out the beaker as many times as possible with distilled deionized water. Dilute the sample to volume and shake.
- 9.3.12 Transfer contents of the volumetric flask to a 100 mL beaker. (j) (j) Do not rinse out the flask until step 9.3.15.
- 9.3.13 Pipet 1.0 mL of this solution with an Eppendorff Pipet into a 10 mL volumetric flask and dilute to the mark.
- 9.3.14 Determine bismuth by atomic absorption spectrometry. (k) (k) This determines the recovery of bismuth through the extraction procedure. See Appendix II for details.
- 9.3.15 Rinse out the 25 mL volumetric flask three times with distilled deionized water into the 100 mL beaker.
- 9.3.16 Add 1.0 mL bismuth carrier.
- 9.3.17 Add ammonium hydroxide until a white precipitate forms. Add dropwise until no further precipitation occurs.
- 9.3.18 Heat on the hot plate for 10 minutes.

- 9.3.19 Remove and filter through 0.6µm PVC filter paper. Wash down sides of chimney two times with distilled deionized water and two times with 30% ethanol.
- 9.3.20 Place the filter paper back into its original 100 mL beaker.
- 9.3.21 Add 5 drops of HCl (sp. gr. 1.19). Stir the filter paper around in the acid until the precipitate dissolves.
- 9.3.22 Wash the filter paper off with distilled deionized water by holding the paper with tweezers into the 100 mL beaker until a final volume of 40 mL is reached.
- 9.3.23 Discard the filter paper.
- 9.3.24 Heat the sample on a hot plate for 10 minutes.
- 9.3.25 Remove and filter through a 0.6µm PVC membrane filter. Police the beaker and rinse the sides of the chimney two times with 30% ethanol. (1) (1) Do not rinse with water as this promotes creep of the precipitate up the walls of the chimney.
- 9.3.26 Remove the filter paper and place on a stainless steel planchet.
- 9.3.27 Dry under a heat lamp.
- 9.3.28 Wrap aluminum foil around planchet.
- 9.3.29 Beta count on a low background counter, noting the time when the count was started.

9.4 Instrument Conditions

9.4.1 Low Background Alpha Beta Counter (Canberra 2200;

(a) Applied Voltage	1430 B
(b) Fine Gain (sample)	0
(c) Coarse Gain (sample)	16
(d) Fine Gain (guard)	0
(e) Coarse Gain (guard)	16
(f) Sample Window	3.70
(g) Count Time	variable

²¹⁰Pb beta counts found in channel B.

9.4.2 Atomic Absorption Spectrometer

(a) Lamp Current (B1)	8mA
(b) Burner Height	7.5 mm
(c) Flame	Air/Acetylene
(d) Wavelength	222.7nm
(e) P.M. Voltage	429.8V
(f) Slit	0.2nm
(g) Mode	Absorption
(h) Damp	B
(i) Air pressure	6psi
(j) Acetylene	2psi

10. Calculations

The following equation is used to determine the concentration of ²¹⁰Pb in a sample. To convert mBq/L to pCi/L divide result by 37.

$$\lambda_s \text{ (mBq/L)} = \frac{\left(\frac{K}{\epsilon \times R_s} \right) \left(N_s - N_b \right) \exp \left[\lambda \left(t_{s2} + \frac{t_s}{2} \right) \right]}{2.22 V_s [1 - \exp(-\lambda t_{s1})]} - B1$$

Where λ_s is the activity of the sample in mBq/L.

K is the correction factor for the sample not counted due to its use in recovery determinations. This factor is 25/24.

ϵ is the detector efficiency. (see Appendix I).

R_s is the recovery of the bismuth through the extraction process (see Appendix II).

N_2 is the gross count rate of the sample plus the background in counts/minute (c/min).

N_b is the background count rate (c/min).

λ is the decay constant for ^{210}Pb which is $0.000096 \text{ min}^{-1}$.

t_{s2} is the time between the start of the sample count and the last set of extractions in minutes.

t_s is the count time for the sample in minutes.

V_s is the volume of the sample in litres.

T_{s1} is the time between the first and second extractions in minutes.

$B1$ is the value for the blank in mBq/L .

Appendix I

Determination of Efficiency for a Low Background Alpha-Beta Counter

1. Prepare three standards according to the following method.
2. Place a stainless steel planchet on a very flat surface under a heat lamp.
3. Place a hydrophobic membrane filter in the planchet.
4. Carefully pipet 1.0 mL of a ²¹⁰Pb/²¹⁰Bi standard (>37 mBq/L - in equilibrium) on to the surface of the filter paper making sure the solution does not spread onto the planchet.
5. Slowly evaporate the solution away.
6. Count the sample on the alpha/beta counter for >1 hour and determine the efficiency via the following equation:

$$E = \frac{R_s - R_B}{D_s}$$

where E is the efficiency (c/d)

R_s is the standards count rate (c/min)

R_B is the background count rate (c/min)

D_s is the disintegration rate (d/min)

7. Determine the average of the three results which are used in 10.1.

Appendix II

Determination of Recovery of Bismuth Through Extraction Procedure

1. Prepare Bismuth standards of 0.0, 0.6, 1, 2, 3, 4 ppm in 2% nitric acid. These correspond to recoveries of 0, 15, 25, 50, 75 and 100%.
2. Obtain absorbance values on the atomic absorption spectrometer using the instrument conditions given 9.4.2, and draw a best fit standard curve plotting recovery vs absorbance or determine a regression line of the form $Y = mx + b$ where Y is the recovery m is the slope of the line, x is the absorbance and b the Y axis intercept.
3. Obtain absorbance values on the atomic absorption spectrometer for samples obtained in 9.3.14. Absorbance values from these measurements can be used directly with working curve or regression line to determine recovery. This value is used in 10.1 to determine ²¹⁰Pb concentration.

APPENDIX B. Efficiency Calculations

Using the method outlined in Appendix I of the attached method the efficiency was calculated as follows:

12510 counts of ^{210}Bi (3.42 Bq/mL) in equilibrium with ^{210}Pb were found in 200 minutes. The background is 11416 counts in 5040 minutes.

∴ the efficiency (E) =

$$\frac{12510 \pm \sqrt{12510}}{200 \text{ min} \times 60 \frac{\text{sec}}{\text{min}}} - \frac{11416 \pm \sqrt{11416}}{5040 \text{ min} \times 60 \frac{\text{sec}}{\text{min}}}$$

$$3.42 \text{ Bq}$$

$$= \frac{1.042 \pm 0.009 \text{ cps} - 0.0378 \pm 0.0004}{3.42 \text{ dps}} = 0.294 \text{ cpd}$$

$$\text{the uncertainty} = \frac{[(0.009)^2 + (0.0004)^2]^{1/2}}{3.42 \text{ Bq}} = 0.003 \text{ cpd}$$

∴ our efficiency was found to be $0.294 \pm 0.003 \text{ cpd}$.

In order to verify this the 25.3 Bq/mL solution was analyzed where the efficiency E is:

$$E = \frac{\left(\frac{K}{\text{Rec}}\right) (N_s - N_B) \exp [\lambda(ts_2 + ts/2)]}{\text{Activity of the sample}}$$

where K is the correction factor for the sample not counted due to its use in the recovery calculations.

Rec is the bismuth recovery through the extraction stage

N_S is the gross count rate of the sample plus the background (cpm)

N_B is the background count rate (cpm)

λ is the decay constant for ^{210}Bi which is $0.000096 \text{ min}^{-1}$

ts2 is the time between the start of the sample count and the last extraction

ts/2 is the count time divided by two.

Working through each term individually:

$$(a) K = \frac{25 \pm 0.03}{24 \pm 0.03} \quad \text{uncertainty} = 1.042 \left[\left(\frac{0.03}{25} \right)^2 + \left(\frac{0.03}{24} \right)^2 \right]^{1/2}$$

$$= 1.042 \quad = 0.002$$

$$\therefore K = 1.042 \pm 0.002$$

$$(b) \text{Rec} = 0.96 \pm 0.02 \text{ (determined by atomic absorption).}$$

$$(c) N_S = 31,904 \text{ counts in 90 minutes}$$

$$N_B = 11,416 \text{ counts in 5040 minutes}$$

$$\therefore N_S - N_B = \frac{[31904 \pm \sqrt{31904}]}{90 \text{ min}} - \frac{[11416 \pm \sqrt{11416}]}{5040 \text{ min}}$$

$$= 352 \text{ cpm}$$

$$\text{uncertainty} = 352 \left[\left(\frac{\sqrt{31904}}{90} \right)^2 + \left(\frac{\sqrt{11416}}{5040} \right)^2 \right]^{1/2} = 2$$

$$\therefore N_S - N_B = 352 \pm 2 \text{ cpm}$$

$$(d) \exp (\lambda(ts2+ts/2))$$

$$ts2 = 1600 \pm 10 \text{ minutes}$$

$$ts/2 = 45 \pm 0.04 \text{ minutes (negligible)}$$

$$e^{(0.000096)(1645)} = 1.1711$$

$$\text{uncertainty} = (0.000096 \times 1645) \left[\frac{10^2}{1600} \right]^{1/2} = 0.001$$

$$\therefore \exp (\lambda(ts2+ts/2)) = 1.171 \pm 0.001$$

$$(e) \therefore \text{efficiency} = \frac{\left(\frac{1.042 \pm 0.002}{0.96 \pm 0.05} \right) (352 \pm 2 \text{ cpr}) (1.171 \pm 0.001)}{60 \frac{\text{sec}}{\text{min}} \times 25.3 \text{ dps}}$$

$$= 0.295$$

$$\text{Uncertainty} = \left[\left(\frac{0.002}{1.042} \right)^2 + \left(\frac{0.02}{0.96} \right)^2 + \left(\frac{2}{352} \right)^2 + \left(\frac{0.001}{1.171} \right)^2 \right]^{1/2} \times 0.295$$

$$= 0.006$$

$$\therefore \text{efficiency} = 0.295 \pm 0.006$$

An analysis of a second sub-sample yielded a result of 0.299 ± 0.006 .

As the efficiency using the method in Appendix I of our method has fewer terms and appears to be correct from the above calculations it was used for all subsequent calculations.

Determined Activity Uncertainty

equation

$$^{210}\text{Pb} = \frac{\left(\frac{K}{E \cdot \text{Rec}}\right) (N_s - N_B) \exp\left(\lambda(ts_2 + ts/2)\right)}{\text{aliquot} (1 - \exp(-\lambda ts_1))}$$

Note: As the samples were in equilibrium the term $1 - \exp(-\lambda ts_1) = 1$. All terms have similar definitives as before where E = efficiency, aliquot = sample aliquot.

Therefore for sample DH1(a) with subsample mass
 1.1453 ± 0.0002 g

$$E = 0.294 \pm 0.003$$

$$K = 1.042 \pm 0.002$$

$$\text{Rec} = 1.00 \pm 0.02$$

$$N_s = \frac{15639 \text{ counts}}{90 \text{ minutes}} = 173.8 \text{ cpm} \quad \text{uncertainty} = \frac{\sqrt{15639}}{90 \text{ min}} = 1.4 \text{ cpm}$$

$$N_B = \frac{11416 \text{ counts}}{5040 \text{ minutes}} = 2.27 \text{ cpm} \quad \text{uncertainty} = \frac{\sqrt{11416}}{5040 \text{ min}} = 0.02$$

$$N_s - N_B = 173.8 - 2.3 = 171.5$$

$$\text{Uncertainty} = (1.4^2 + 0.02^2)^{1/2} = 1.4$$

$$\therefore (N_s - N_B) = 171.5 \pm 1.4 \text{ cpm}$$

$$ts_2 = 255 \pm 5 \text{ min}$$

$$\therefore ts_2 + ts/2 = 300 \pm 5 \text{ min}$$

$$ts/2 = 45 \pm 0.04 \text{ min}$$

$$\lambda = 0.000096 \text{ min}^{-1}$$

$$\exp(\lambda(ts_2 + ts/2)) = \exp(0.000096 \times 300) = 1.0292$$

$$\text{uncertainty} = 0.000096 \times 300 \left(\left(\frac{5}{300} \right)^2 \right)^{1/2} = 0.0005$$

$$\therefore \exp(\lambda(ts_2 + ts/2)) = 1.0292 \pm 0.0005$$

$$\text{Aliquot} = 100 \pm 0.08 \text{ mL of } 1.1453 \pm 0.0002 \text{ g into } 250 \pm 0.12 \text{ mL}$$

$$\therefore \text{total activity} =$$

$$\frac{\left(\frac{1.042}{(0.294)(1.00)} \right) 171.5 \text{ cpm } (1.0292)}{\frac{100}{250} \times 1.1453 \times 60 \frac{\text{sec}}{\text{min}}} = 22.7 \text{ Bq/g}$$

$$\text{uncertainty} =$$

$$22.7 \left[\left(\frac{0.003}{0.294} \right)^2 + \left(\frac{0.002}{1.042} \right)^2 + \left(\frac{0.02}{1.00} \right)^2 + \left(\frac{1.4}{171.5} \right)^2 + \left(\frac{0.0005}{1.0292} \right)^2 + \left(\frac{0.08}{100} \right)^2 + \left(\frac{0.002}{1.1453} \right)^2 + \left(\frac{0.12}{250} \right)^2 \right]^{1/2}$$

$$= 0.55$$

$$95\% \text{ C.L.} = 0.55 \times 1.96 = 1.1$$

$$\therefore \text{activity} = 22.7 \pm 1.1$$

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